Charmless b hadron decays at CDF

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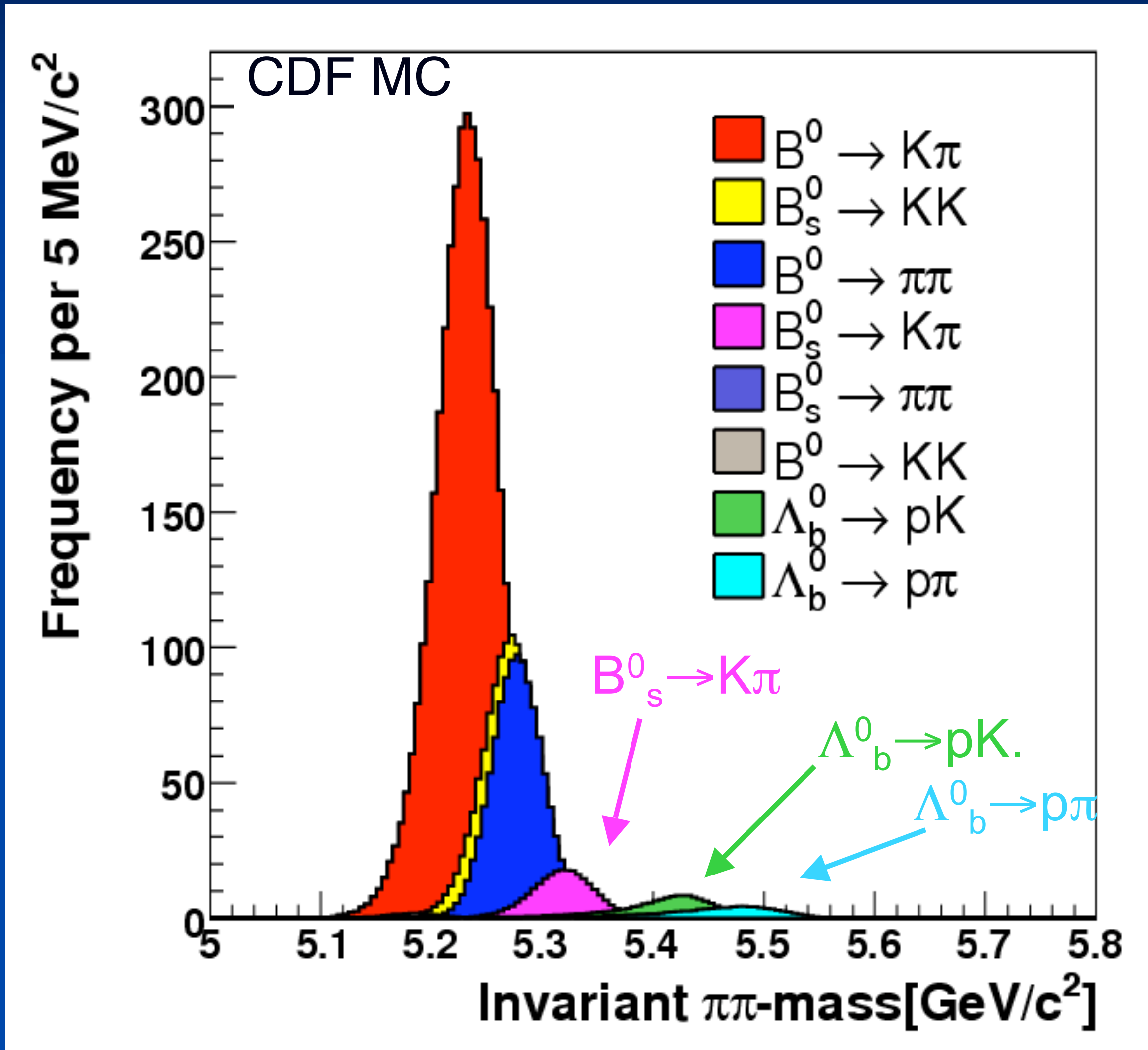
$B^0_{(s)} \rightarrow h^+h'^-$ and $\Lambda^0_b \rightarrow ph^-$ at CDF motivations

- For the first time amazing possibilities for probing into dynamics of all charmless charged decays of b-hadrons.
- Different processes sensitive to same UT angles (i.e. γ) $\Rightarrow$ probe for EW structure of SM .
- Contributions of new particles may enter in penguin diagrams $\Rightarrow$ probe for New Physics.
- Program complementary to other experiments: simultaneous measurements of B^0, **B^0_s and Λ^0_b**.

Very rich phenomenology but "challenging" measurement

$B^0_{(s)} \to h^+h'^-$ at CDF



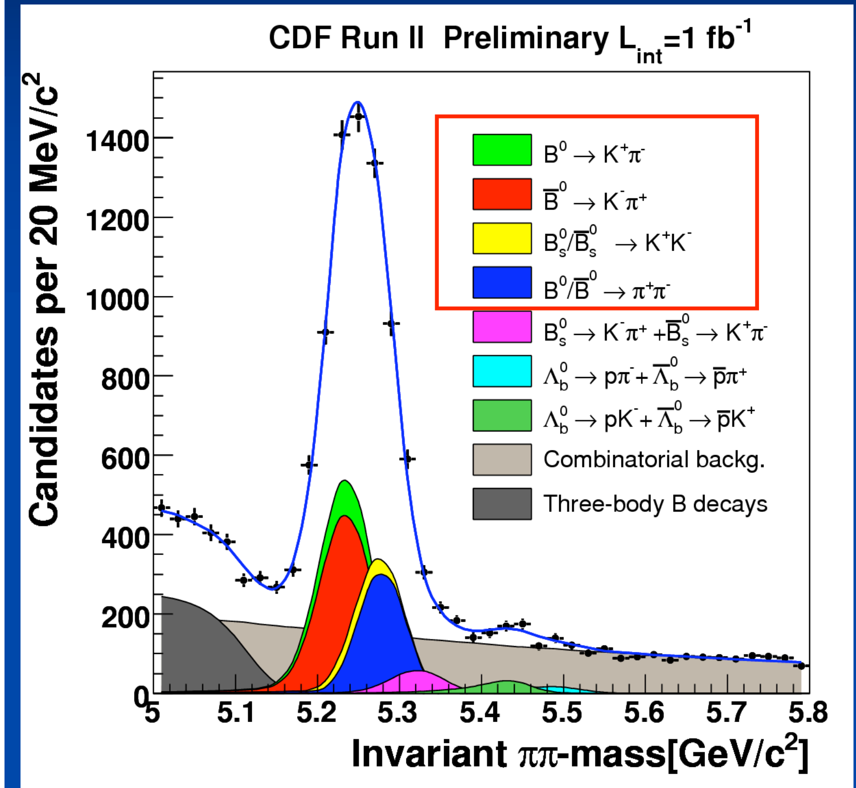
Despite good mass resolution ($\cong$22 MeV/c^2), individual modes overlap in a single peak (width ~35 MeV/c^2)

Note that the use of a single mass assignment ($\pi\pi$) causes overlap even with perfect resolution

Each mode is a background for others. i.e. $\Lambda^0_b \to p\pi$/pK are "backgrounds" of $B^0_s \to K\pi$ "signal". Also the large modes are background for $B^0_s \to K\pi$ "signal".

Need to determine signal composition with a **Likelihood fit**, combining information from **kinematics** (mass and momenta) and **particle ID** (dE/dx).

Results on "large" modes



B^0 yields comparable to e^+e^-
4045 ± 84 $B^0 \to K^+\pi^-$

3.5σ

$$A_{CP}(B^0 \to K^+\pi^-) = -0.086 \pm 0.023(stat.) \pm 0.09(syst.)$$

Goal with Full Run II statistics ~1%

In agreement with e^+e^- experiments:

$$BaBar(467\,MB\overline{B}) \Rightarrow A_{CP} = -0.107 \pm 0.016^{+0.006}_{-0.004}$$
$$Belle(532\,MB\overline{B}) \Rightarrow A_{CP} = -0.094 \pm 0.018 \pm 0.008$$

With the same selection performed high precision measurements of:

$$\frac{BR(B^0 \to \pi^+\pi^-)}{BR(B^0 \to K^+\pi^-)} = 0.259 \pm 0.017(stat.) \pm 0.016(syst.)$$

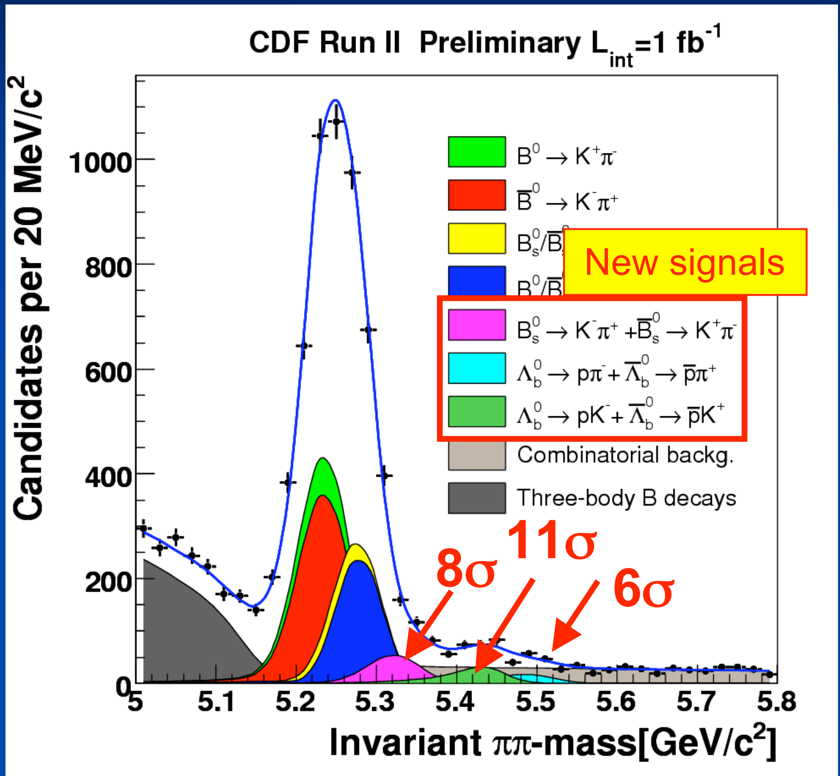
good agreement with e^+e^- experiments, Belle measures 0.26±0.01±0.01 with 449MBBbar.

Largest sample of $B^0_s \to K^+K^- \approx 1300 \Rightarrow$

$$\frac{f_s}{f_d} \times \frac{BR(B_s^0 \to K^+K^-)}{BR(B^0 \to K^+\pi^-)} = 0.347 \pm 0.020(stat.) \pm 0.021(syst.)$$

http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/

First observation of $B^0_s \to K^-\pi^+$



Selection optimized to observe the rare $B^0_s \to K^-\pi^+$ mode.

First observation of $B^0_s \to K^-\pi^+$ charmless decay with 8σ of significance

$$\frac{f_s}{f_d} \times \frac{BR(B^0_s \to K^-\pi^+)}{BR(B^0 \to K^+\pi^-)} = 0.071 \pm 0.010(stat.) \pm 0.007(syst.)$$

Using PDG08 inputs:

$$BR(B^0_s \to K^-\pi^+) = (5.0 \pm 0.7(stat.) \pm 0.8(syst.)) \times 10^{-6}$$

As a "background" first observation of two baryonic charmless decays: $\Lambda^0_b \to p\pi^-$ (6σ) and $\Lambda^0_b \to pK^-$ (11σ)

$BR(B^0_s \to K^-\pi^+)$ theoretical expectations are strongly related to α and γ:
QCDF, pQCD [6-10] $\cdot 10^{-6}$
[NP B675, 333(2003); PRD71,074026 (2005)]
SCET: $(4.9 \pm 1.8) \cdot 10^{-6}$ *[PRD74, 014003(2006)]*

http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/

Direct CPV $B^0_s \to K^-\pi^+$

Observation of this decay offers a unique opportunity of checking for the SM origin of direct CP violation. Proposed in *[Gronau, Phys.Lett. B492, 297 (2000)],* later shown to hold under much weaker assumptions in *[Lipkin, Phys. Lett. B621,126, (2005)]*.

$$\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-) = \Gamma(B^0_s \to K^-\pi^+) - \Gamma(\overline{B}^0_s \to K^+\pi^-)$$

Currently unique to CDF. From our measured BR, we can predict DCPV using:

$$A_{CP}(B^0_s \to K^-\pi^+) = -A_{CP}(B^0 \to K^+\pi^-) \cdot \frac{BR(B^0 \to K^+\pi^-)}{BR(B^0_s \to K^-\pi^+)} \cdot \frac{\tau(B^0)}{\tau(B^0_s)}$$

Low BR($B^0_s \to K^+\pi^-$) implies large asymmetry: DCPV≅ **+40%**

Interesting case of large DCPV predicted under SM

Direct CPV in $B^0_s \to K^-\pi^+$ (cont'd)

2.5σ

$$A_{CP}(B_s^0 \to K^-\pi^+) = \frac{BR(\overline{B}_s^0 \to K^+\pi^-) - BR(B_s^0 \to K^-\pi^+)}{BR(\overline{B}_s^0 \to K^+\pi^-) + BR(B_s^0 \to K^-\pi^+)} = 0.39 \pm 0.15(stat.) \pm 0.08(syst.)$$

Using PDG08 inputs for f_s and f_d:

$$\frac{\Gamma(\overline{B}^0 \to K^-\pi^+) - \Gamma(B^0 \to K^+\pi^-)}{\Gamma(\overline{B}_s^0 \to K^+\pi^-) - \Gamma(B_s^0 \to K^-\pi^+)} = -0.83 \pm 0.41(stat.) \pm 0.12(syst.)$$

(SM = -1)

First measurement of DCPV in the B^0_s

Sign and magnitude agree with SM predictions within uncertainties.

May shed light on the Belle and BaBar discrepancy. Assuming perfect SU(3) symmetry and neglecting annihilation diagrams *[Nucl. Phys. B697, 133,2004]* :

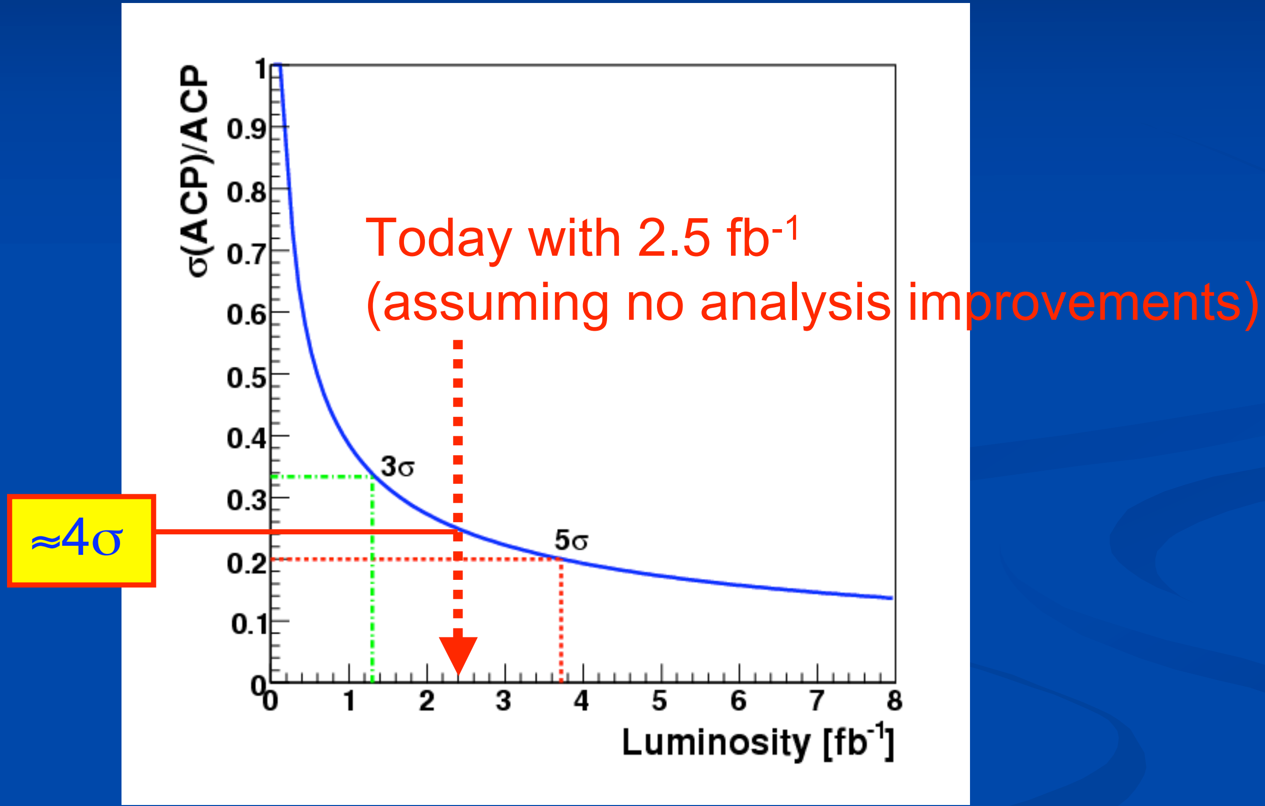
$A_{CP}(B^0 \to \pi^+\pi^-) = A_{CP}(B^0_s \to K^-\pi^+)$.

Note that our central value for A_{CP} is just in the middle of B-Factories results.

http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/

DCPV $B^0_s \to K^-\pi^+$: prospect

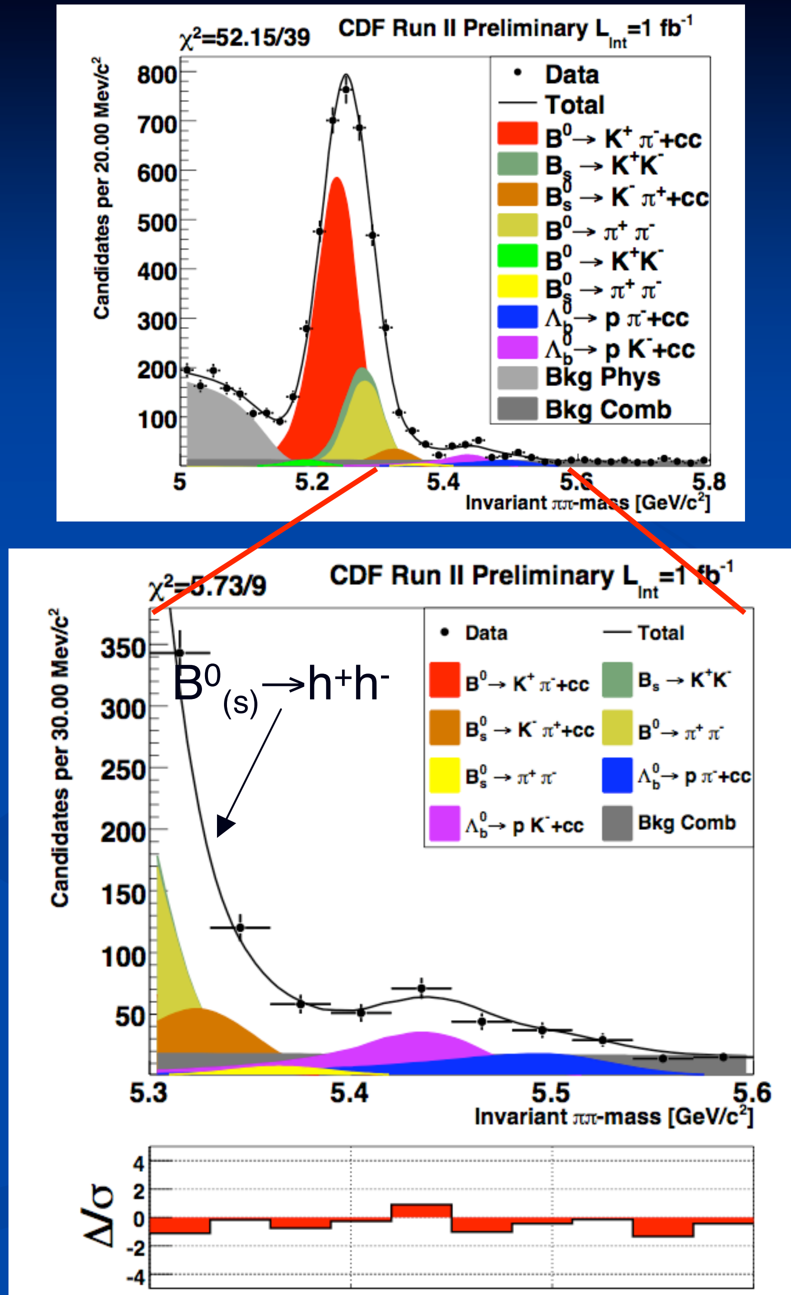
Assuming SM hypothesis ⇒ Gronau-Lipkin relation true



Expected improvements in the analysis to approach 5σ.
Very exciting to pursue with more data, in any case !

$\Lambda^0_b \to p h^-$ decays

- $\Lambda^0_b \to p h^-$ amazing "background" of $B^0_{(s)} \to h^+ h^-$.
  - First insight to dynamics of b-baryon charmless decays.
  - CPV may reach significant size O(10%) in SM.
- BR/A_{CP} needed additional work with respect to standard $B \to hh$ analysis:
  - Λ^0_b p_T spectrum is different from B
  - Λ^0_b polarization modifies kinematics
  - Evaluation of p/K, p/π and p/$\bar{p}$ efficiencies due to the presence of a proton in the final state.
- Additional cut on $p_T(\Lambda^0_b)$>6GeV/c is needed because it has been measured in CDF only above this threshold.



BR/DCPV in $\Lambda^0_b \to ph^-$

$$\frac{f_\Lambda}{f_d} \times \frac{BR(\Lambda_b^0 \to p\pi^-)}{BR(B^0 \to K^+\pi^-)} = 0.042 \pm 0.007(stat.) \pm 0.006(syst.)$$

$$\frac{f_\Lambda}{f_d} \times \frac{BR(\Lambda_b^0 \to pK^-)}{BR(B^0 \to K^+\pi^-)} = 0.066 \pm 0.009(stat.) \pm 0.008(syst.)$$

BRs are in agreement with SM predictions and exclude BR≈O(10^{-4}) values indicated for R-parity violating Minimal Supersymmetric extensions of the SM model. *[PRD63,056006(2001)]*

First DCPV measurements in b-hadrons decays. Statistical uncertainty dominates.
Hint of DCPV in baryon decays. Very interesting to pursue with more data.

2.1σ

$$A_{CP}(\Lambda_b^0 \to pK^-) = -0.37 \pm 0.17(stat.) \pm 0.03(syst.)$$

$$A_{CP}(\Lambda_b^0 \to p\pi^-) = -0.03 \pm 0.17(stat.) \pm 0.05(syst.)$$

http://www-cdf.fnal.gov/physics/new/bottom/071018.blessed-ACP_Lambdab_ph

Conclusions

- First observation of $B^0_s \to K^- \pi^+$ mode
- First measurement of DCPV in B^0_s
  - SM prediction of large $A_{CP}(B^0_s \to K^- \pi^+)$ confirmed.
- First observation of $\Lambda^0_b \to pK^-$, $\Lambda^0_b \to p\pi^-$.
  - Measured branching fractions in agreement with SM predictions
  - First measurement of DCPV in a baryonic decays. $A_{CP}(\Lambda^0_b \to pK^-)$ different from 0 by 2.1σ
- Precision $A_{CP}(B^0 \to K^+ \pi^-)$ confirms B-factories results.
  - Expect final measurement with uncertainty ~1% with full RunII statistics.
- Precision measurement of $BR(B^0 \to \pi^+ \pi^-)$ and $BR(B^0_s \to K^+ K^-)$.
- World best upper limit on annihilation mode $BR(B^0_s \to \pi^+ \pi^-) < 1.2 \cdot 10^{-6}$ (90%CL).

- b physics program at CDF very rich and still promising. Two-body charmless decays are golden channels. Several more to follow. Precise measurements of CP asymmetries up-coming.

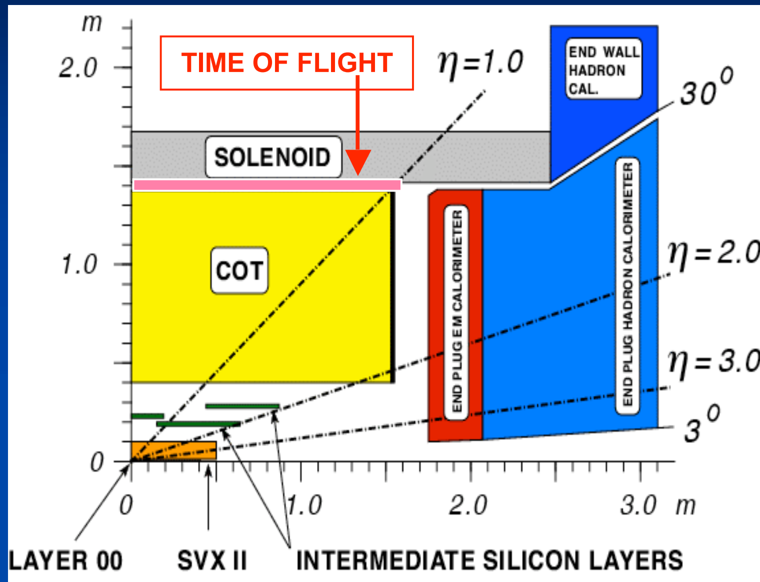
Backup

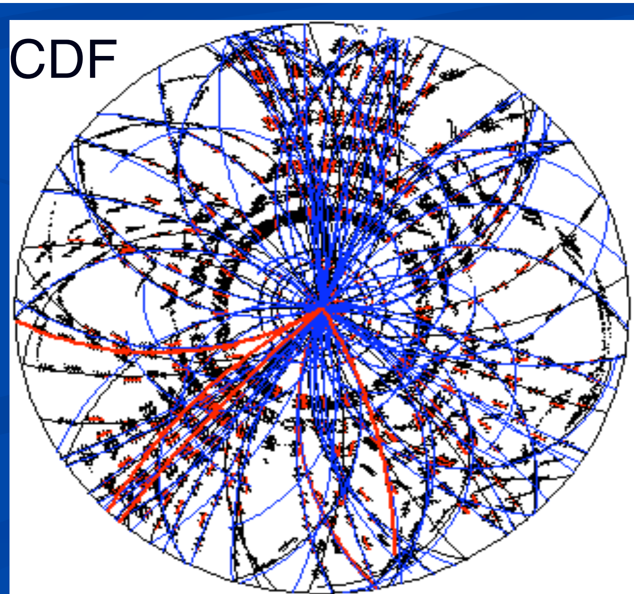
Important CDF features

- Central Drift chamber (COT)
  - $\sigma(p_T)/p_T^{\,2} \sim 0.1\%\ \mathrm{GeV}^{-1}$
  - dE/dx measurement:
    - 1.5σ sep. K/π @ p>2GeV/c.
- Silicon VerteX detector (SVX)
  - I.P. resolution: 35μm @ p=2GeV/c.
- Tracking trigger:
  - On-line impact parameter measurement (crucial)

Total inelastic x-section $\times 10^3$ larger than $\sigma(b\bar{b})$. BRs' for interesting processes $O(10^{-6})$. Messy environments with large combinatorics.

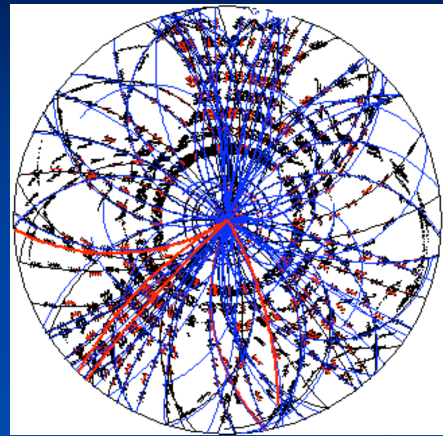
In this talk measurements with $1\mathrm{fb}^{-1}$.





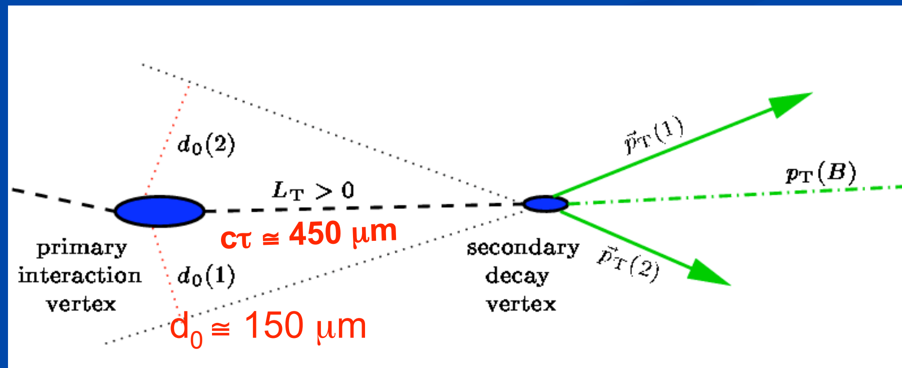
B hadron signature

Total inelastic x-section ×10^3 larger than $\sigma(b\bar{b})$. BRs' for interesting processes O(10^{-6}). Messy environments with large combinatorics.



"Long" (~1.5 ps) lifetime of *b*-hadrons: a powerful signature against light-quark background.

Cut online (L2 trigger) on impact parameter d_0(track).

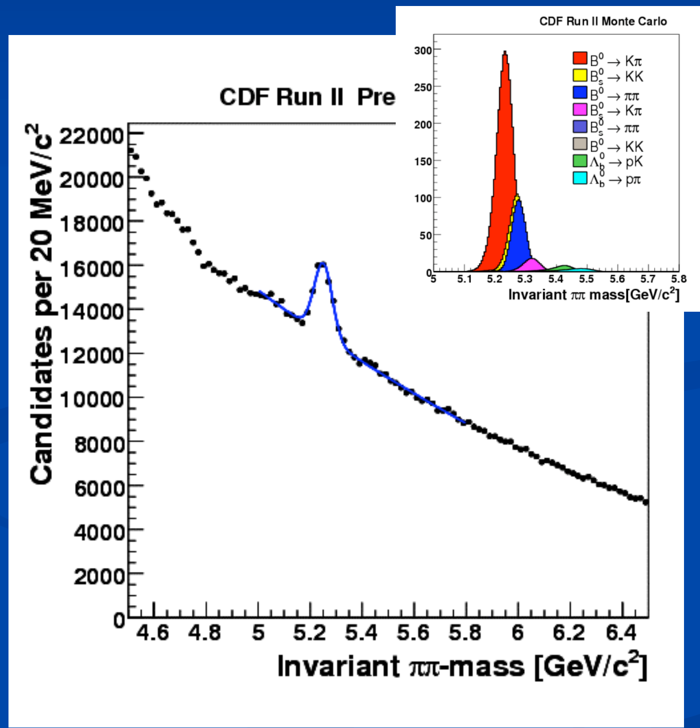


Very high-purity samples of hadronic *B* (and *D)* decays.

It all begins in the trigger

- Two oppositely-charged tracks (i.e. *B* candidate) from a long-lived decay:
  - track's impact parameter;
  - *B* transverse decay length;
- *B* candidate pointing back to primary vertex:
  - impact parameter of the *B*;
- Reject light-quark background from jets:
  - transverse opening angle;
  - p_{T1} and p_{T2} ;
  - $p_{T1}+p_{T2}$.

Signal (BR ~ 10^{-5}) visible with just offline trigger cuts confirmation:



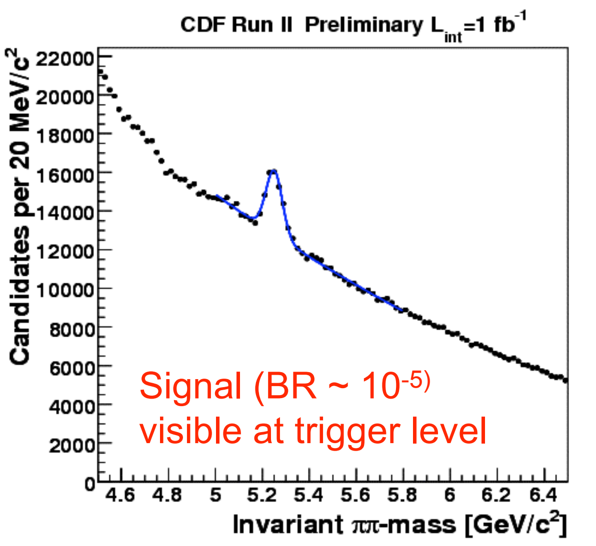
Isolation: I(B) (rejects light quark backg.)
3D vertex quality: χ^2_{3D}(B)

a bump of ~ 14500 events with S/B ≈ 0.2 (at peak) in *ππ*-invariant mass

Sample selection

TRIGGER cuts

- Reject light-quark background
  - Two oppositely-charged tracks
  - Transverse opening angle;
  - p_{T1} , p_{T2};
  - $p_{T1} + p_{T2}$.
- Long-lived candidate
  - Track impact parameters;
  - Transverse decay length;
- Reject multi-prongs and backgrounds
  - B impact parameter.



OFFLINE cuts

- Further observables:
  - 3D Vertex chi-square
  - Isolation:

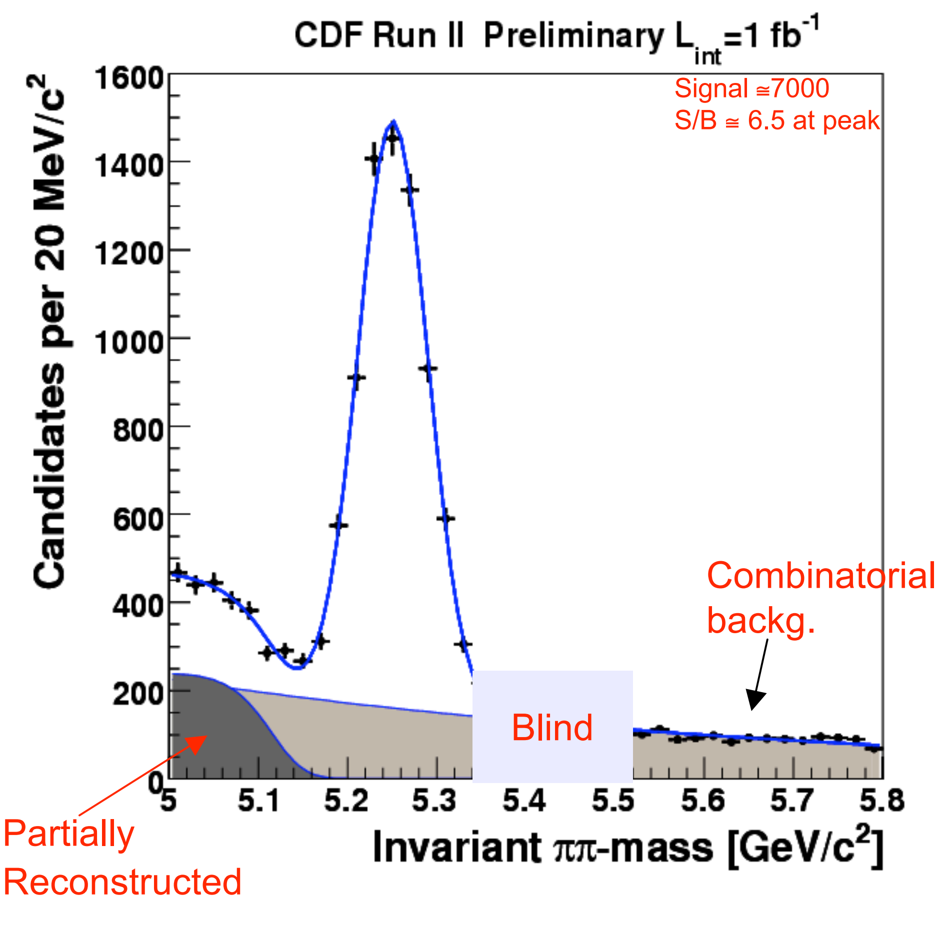
$$I(B) = \frac{p_T(B)}{p_T(B) + \sum_{cone} p_{Ti}}$$

- Effective in reducing light-quark background, 85% efficient. (analog of event shape at e^+e^-)

2 sets of cuts:

- Loose: optimize for $A_{CP}(B^0 \rightarrow K^+\pi^-)$
  (good for all three "large modes")
- Tight: optimize for $B^0_s \rightarrow K^-\pi^+$
  (good for all "rare modes")

$B \to h^+h^-$ signal (loose cuts)



Selection optimized to minimize statistical uncertainty on $A_{CP}(B^0 \to K\pi)$

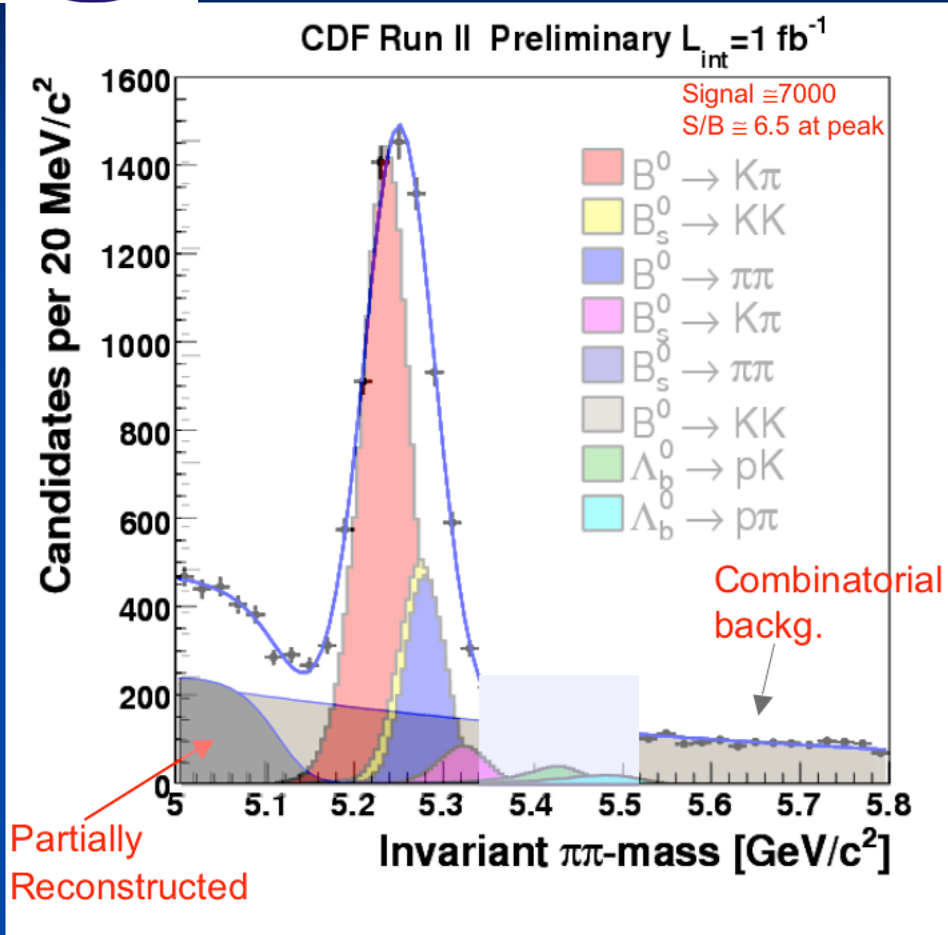
Despite good mass resolution (≅22 MeV/c^2), individual modes overlap in a single peak (width ~35 MeV/c^2)

Note that the use of a single mass assignment (ππ) causes overlap even with perfect resolution.

Blinded region of unobserved modes: $B^0_s \to K\pi$, $B^0_s \to \pi\pi$, $\Lambda^0_b \to p\pi/pK$.

Need to determine signal composition with a **Likelihood fit**, combining information from **kinematics** (mass and momenta) and **particle ID** (dE/dx).

$B \to h^+h^-$ signal (loose cuts)



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Blinded region of unobserved modes: $B^0_s \to K\pi$, $B^0_s \to \pi\pi$, $\Lambda^0_b \to p\pi/pK$.

Need to determine signal composition with a **Likelihood fit**, combining information from **kinematics** (mass and momenta) and **particle ID** (dE/dx).

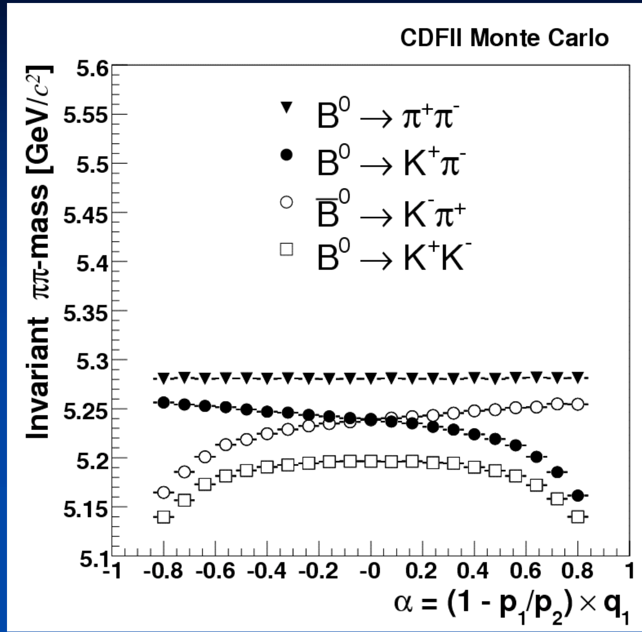
Main analysis ingredients: Kinematics and PID

Exploit dependence between invariant mass and momentum imbalance.

1) $M_{\pi\pi}$ invariant $\pi\pi$-mass

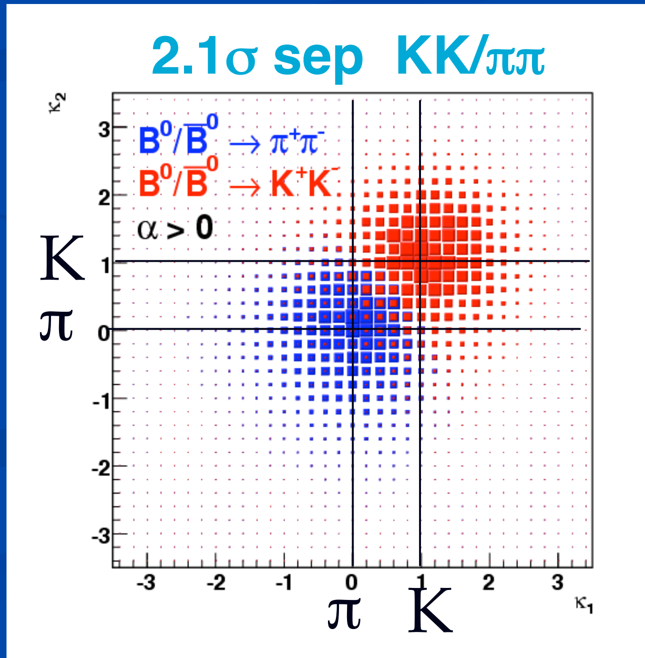
2) $\alpha = (1-p_{min}/p_{max})q_{min}$
signed p-imbalance

3) $p_{tot} = p_{min}+p_{max}$
scalar sum of 3-momenta



dE/dx carefully calibrated on pure K and π samples from 1.5M decays: $D^{*+} \to D^0\pi^+ \to [K^-\pi^+]\pi^+$ (sign of D^{*+} pion tags D^0 sign)

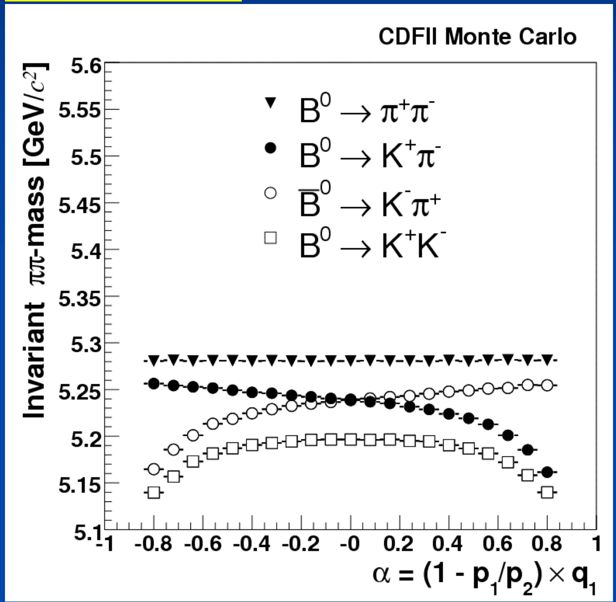
1.5σ K/π power separation for track p>2GeV/c which becomes **2.1**σ for KK/$\pi\pi$ and $K^+\pi^-/\pi^+K^-$.

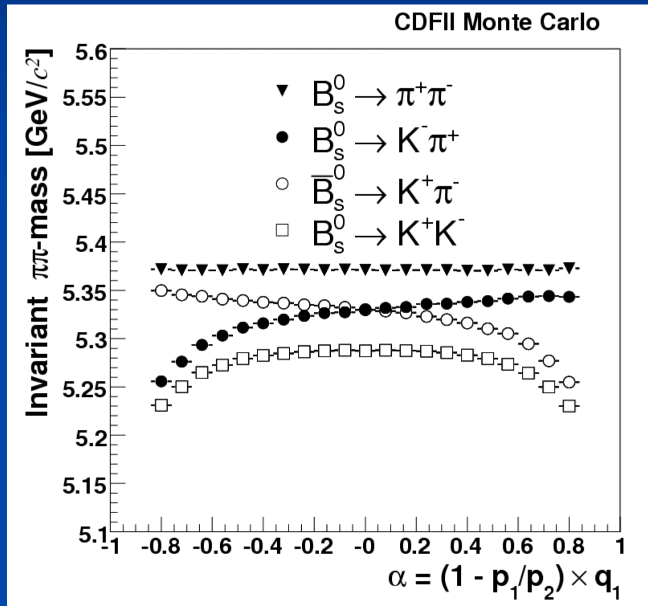


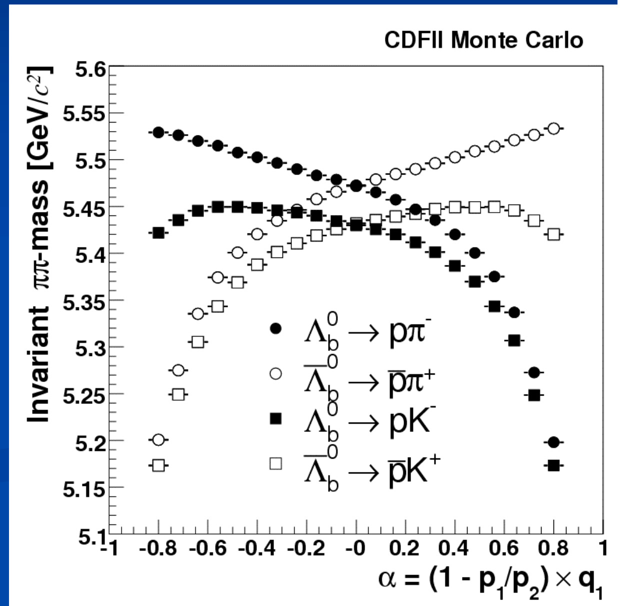
Kinematics

CDF MC

Exploit dependence between invariant mass
and momentum imbalance







1) $M_{\pi\pi}$ invariant ππ-mass

2) $\alpha = (1-p_{min}/p_{max})q_{min}$ signed p-imbalance

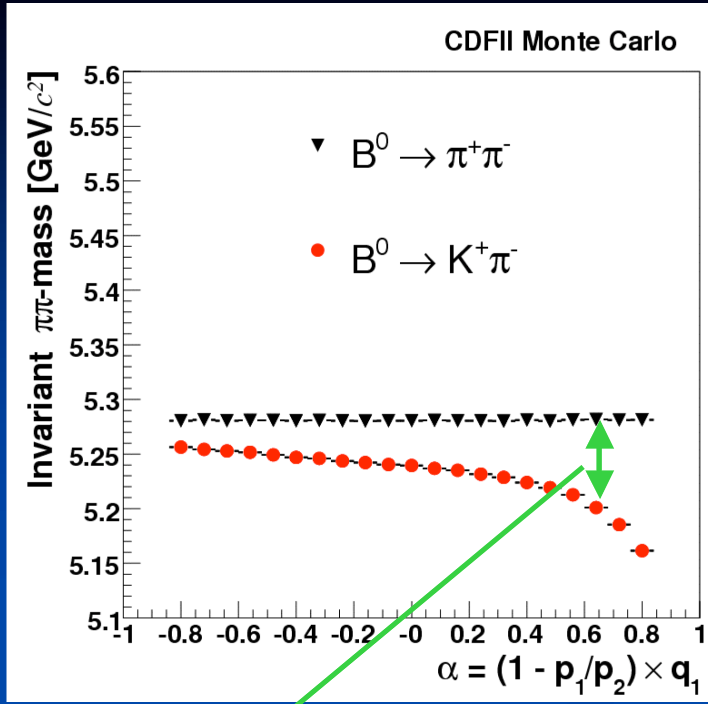
3) $p_{tot} = p_{min}+p_{max}$ scalar sum of 3-momenta

This offers good discrimination amongst modes and between $K^+\pi^-$ / $K^-\pi^+$.

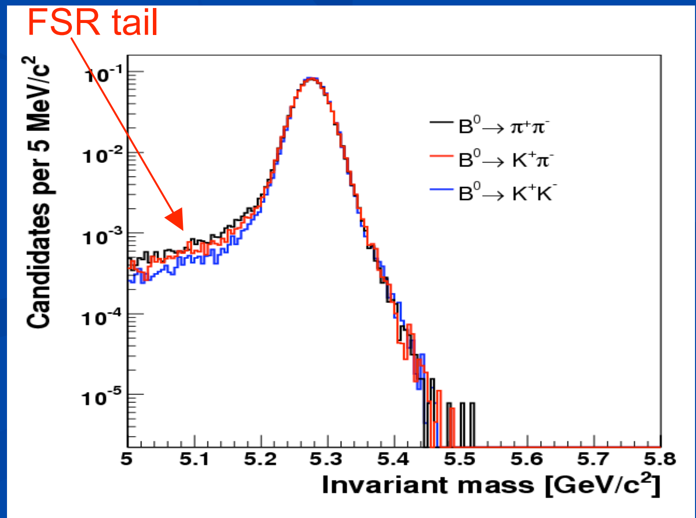
Kinematics

Exploit dependence between invariant mass and momentum imbalance. This offers good discrimination amongst modes and between $K^+\pi^-$ / $K^-\pi^+$.

1) $M_{\pi\pi}$ invariant $\pi\pi$-mass
2) $\alpha = (1-p_{min}/p_{max})q_{min}$
   signed p-imbalance
3) $p_{tot} = p_{min}+p_{max}$
   scalar sum of 3-momenta



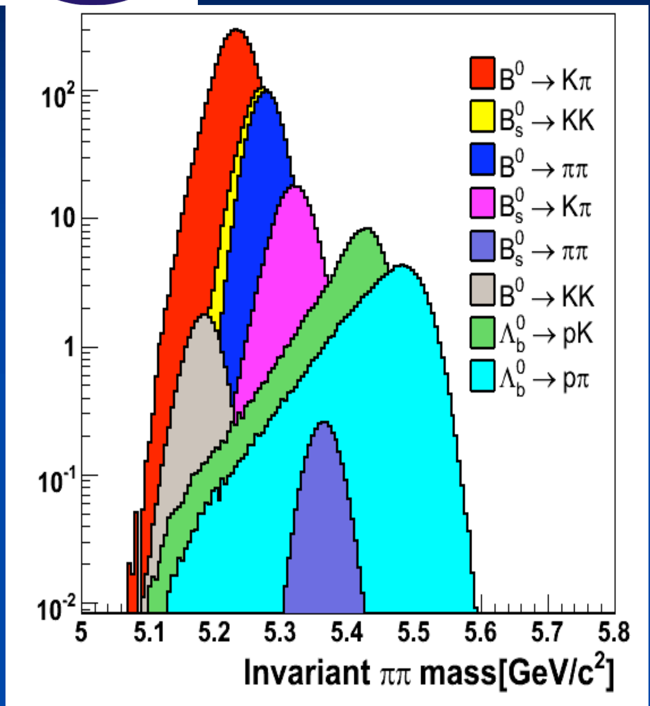
analytical function of momenta $\mathbf{f(\alpha,p_{tot})}$



Results depend on assumed mass resolution and details of the lineshape

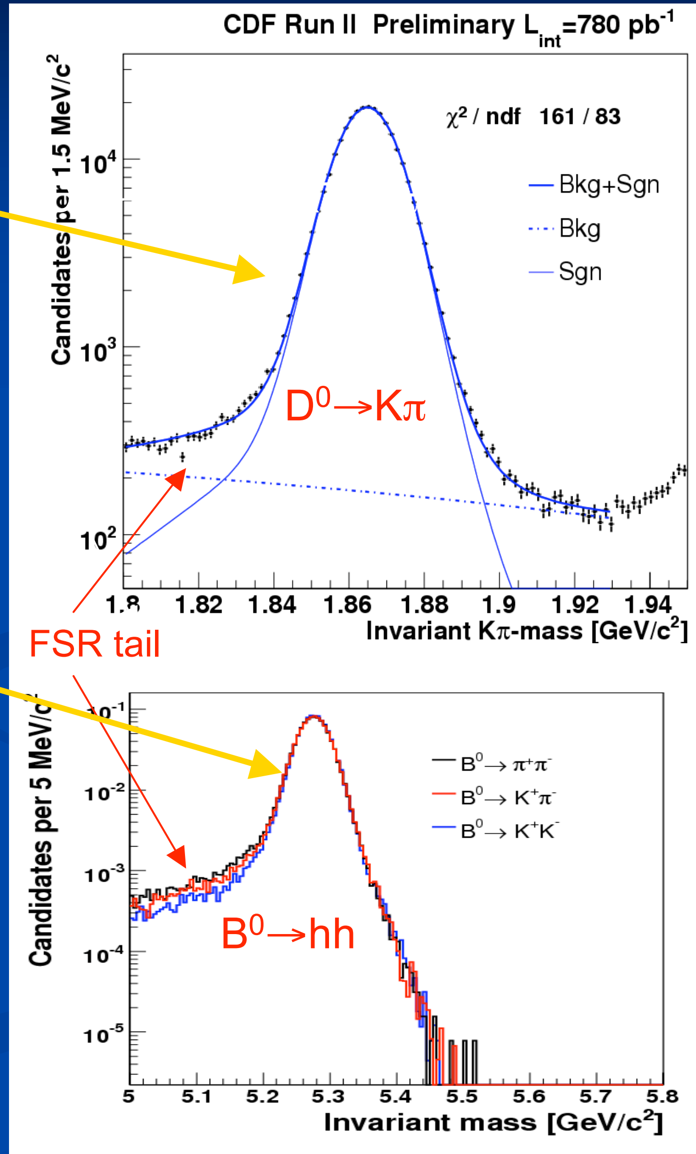
Final State Radiation treated in the simulation using *QED: [Baracchini,Isidori PRL B633:309-313,2006]* .
Check on 1.5M of $D^{*+} \rightarrow D^0\pi^+ \rightarrow [K^-\pi^+]\,\pi^+$

Mass line shape and FSR



1) TEST on $D^0 \to K^- \pi^+$

2) APPLY to $B \to h^- h^+$



Results depend on assumed mass resolution and details of the lineshape (rare modes confuse with the tails of larger modes)

Need good control of non–gaussian resolution and effects of Final State Radiation

QED: *[Baracchini,Isidori PL B633:309-313,2006]*

dE/dx

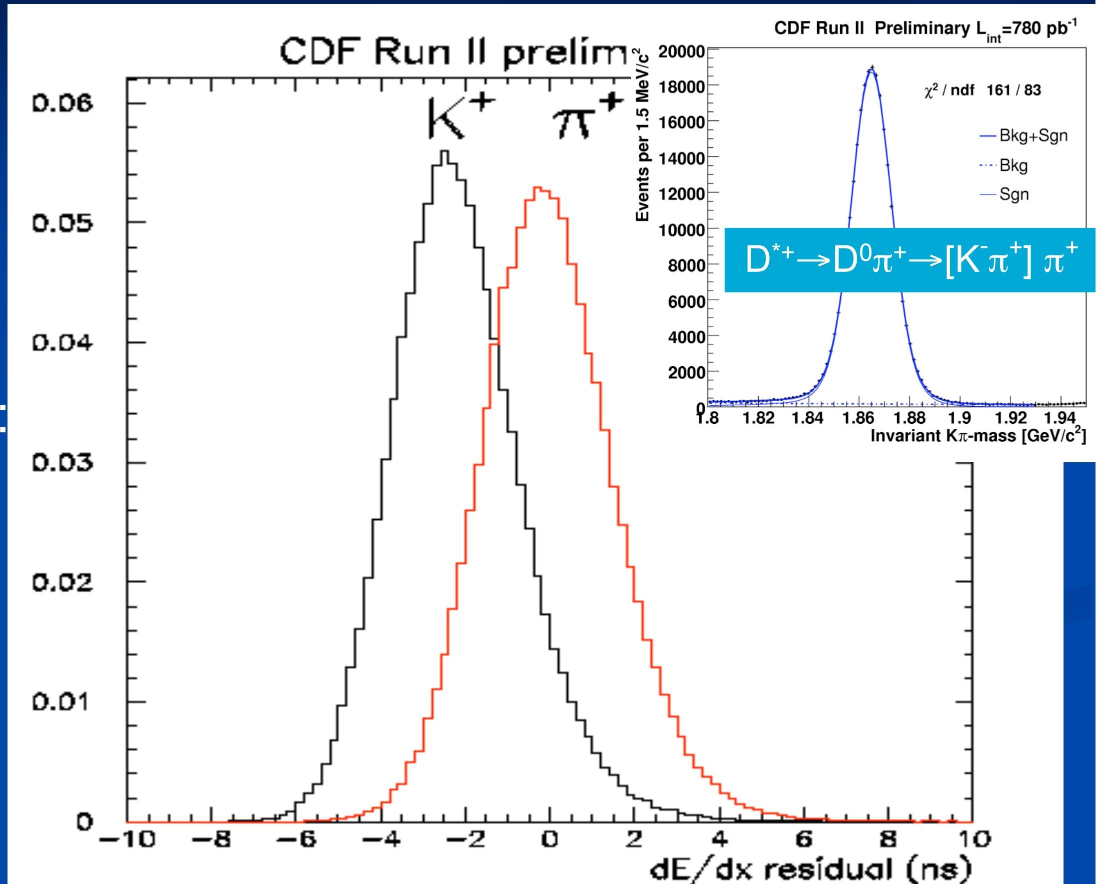
Calibrate on pure K and π samples from decay: $D^{*+} \to D^0 \pi^+ \to [K^- \pi^+]\, \pi^+$
(sign of D^{*+} pion tags D^0 sign)

Useful quantity to plot ('kaonness'):

$$\frac{\left.\frac{dE}{dx}\right|_{\mathrm{meas}}(\mathrm{track}) - \left.\frac{dE}{dx}\right|_{\mathrm{exp}-\pi}(\mathrm{track})}{\left.\frac{dE}{dx}\right|_{\mathrm{exp}-K}(\mathrm{track}) - \left.\frac{dE}{dx}\right|_{\mathrm{exp}-\pi}(\mathrm{track})}.$$

<id>(pion) = 0
<id>(kaon) = 1

(independent of p)



dE/dx carefully calibrated over tracking volume and time.
Detailed model includes tails, momentum dependence, two-track correlations

1.5σ K/π separation for p>2GeV achieve a statistical uncertainty on separating classes of particles which is just 60% worse than 'perfect' PID

$B \to h^+h^-$: dE/dx

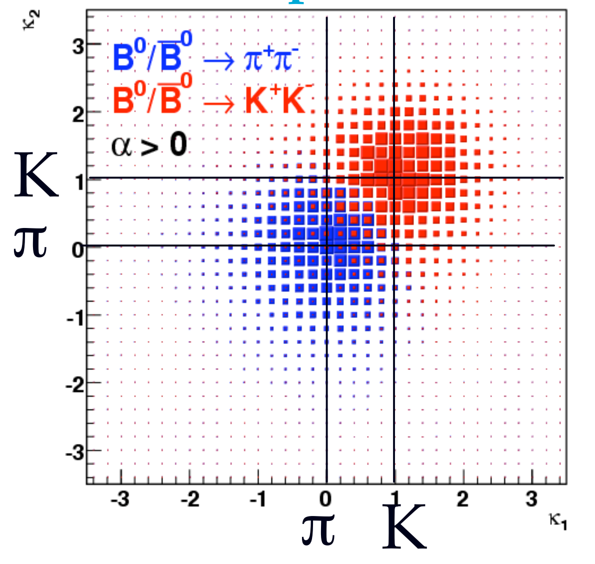
Carefully calibrated on pure K and π samples from 1.5M decays: $D^{*+} \to D^0\pi^+ \to [K^-\pi^+]\,\pi^+$
(sign of D^{*+} pion tags D^0 sign)

Useful dE/dx quantity ('kaonness'):

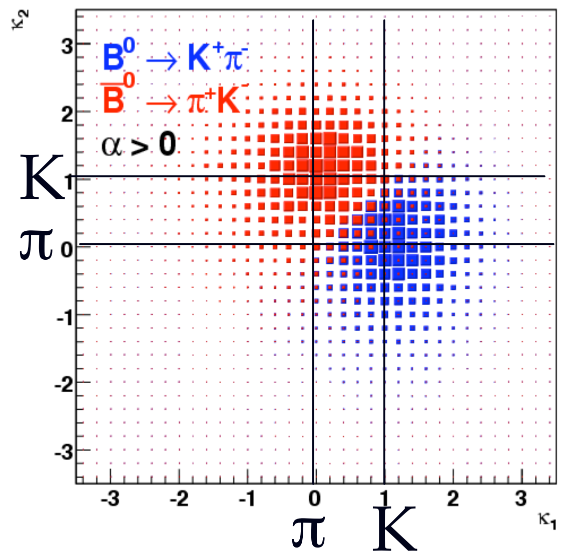
<kaonness>(pion) = 0
<kaonness>(kaon) = 1

1.5σ K/π power separation for track p>2GeV/c achieve a statistical uncertainty on separating classes of particles which is just 60% worse than 'perfect' PID (≡75% for 2 particles)
[arXiv:physics/0611219]

2.1σ sep KK/ππ



2.1σ sep $K^+\pi^-/\pi^+K^-$



Separating channels

Unbinned ML fit based on 5 observables (kinematics+PID)

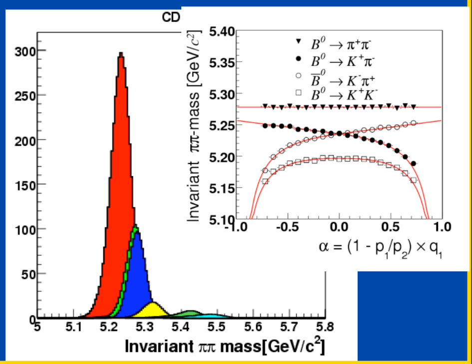
$$\mathscr{L}(\vec{\theta}) = \prod_{i=1}^{N} \mathscr{L}_i(\vec{\theta})$$

fraction of jth mode, to be determined by the fit

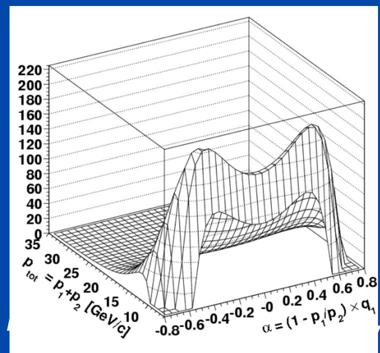
$$\mathscr{L}_i(\vec{\theta}) = (1-b)\sum f_j \mathscr{L}_j^{\mathrm{sign}} + b\mathscr{L}^{\mathrm{bckg}}$$

$$pdf_j^{\mathrm{m}}(m_{\pi\pi}|\alpha, p_{tot};\vec{\theta}) \cdot pdf_j^{\mathrm{p}}(\alpha, p_{tot};\vec{\theta}) \cdot pdf_j^{\mathrm{PID}}(\mathrm{ID}_1, \mathrm{ID}_2|p_{tot}, \alpha;\vec{\theta})$$

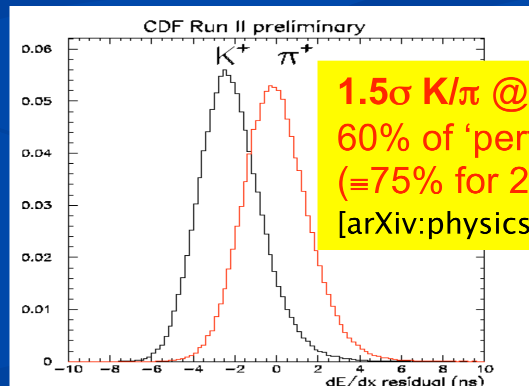
mass term



momentum term



dE/dx term



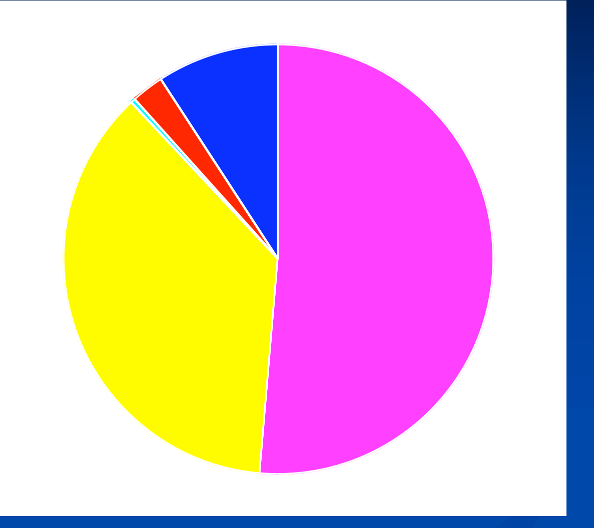
1.5σ K/π @p>2GeV ≡
60% of 'perfect' PID
(≡75% for 2 particles)
[arXiv:physics/0611219]

Signal shapes: from MC and analytic formula
Background shapes: from data sidebands

sign and bckg shapes from $D^0 \to K^-\pi^+$

Systematics $A_{CP}(B^0 \to K^+\pi^-)$

- dE/dx model (±0.0064);
- Nominal *B*-meson masses (±0.005);
- Background model (±0.003);
- Charge-asymmetries (±0.0014);
- Global mass scale.



Total systematic uncertainty is 0.9%, compare with 2.3% statistical.

Huge sample of prompt $D^0 \to h^+h^-$ (15M).

Kinematic fit using *same code* of $B \to hh$ fit. Direct $A_{CP}(D^0 \to K\pi)$ very small:

$\Rightarrow$ extract from DATA correction for $\varepsilon(K^-\pi^+)/\varepsilon(K^+\pi^-)$ plus any spurious asymmetries.

Additional check: measurement of $A_{CP}(D^0 \to K\pi)$ based on dE/dx-only.

Discrepancy with the kinematic fit (≅0.006) within quoted systematics.

Systematics can still decrease with larger calibration samples

Prospects for a runII CDF measurement with **≈1% uncertainty**.

BR/DCPV in $\Lambda^0_b \to ph^-$

BRs are in agreement with SM predictions and exclude O(10^{-4}) values indicated for R-parity violating Minimal Supersymmetric extensions of the SM model. *[PRD63,056006(2001)]*

$$\frac{f_\Lambda}{f_d} \times \frac{\mathcal{B}(\Lambda^0_b \to p\pi^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.042 \pm 0.007\ (stat.)\ \pm 0.006\ (syst.)$$

$$\frac{f_\Lambda}{f_d} \times \frac{\mathcal{B}(\Lambda^0_b \to pK^-)}{\mathcal{B}(B^0 \to K^+\pi^-)} = 0.066 \pm 0.009\ (stat.)\ \pm 0.008\ (syst.)$$

Assuming PDG08 value for f_Λ/f_d=0.230±0.052

$$\mathcal{B}(\Lambda^0_b \to p\pi^-) = (3.5 \pm 0.6\ (stat.) \pm 0.9\ (syst.)) \times 10^{-6}$$

$$\mathcal{B}(\Lambda^0_b \to pK^-) = (5.6 \pm 0.7\ (stat.) \pm 1.5\ (syst.)) \times 10^{-6}$$

These are the first DCPV measurements in b-hadrons decays. Statistical uncertainty dominates. First hint of DCPV in baryon decays. Very interesting to pursue with more data.

$$\mathcal{A}_{CP}(\Lambda^0_b \to pK^-) = -0.37 \pm 0.17\ (stat.) \pm 0.03\ (syst.)$$ **2.1σ**

$$\mathcal{A}_{CP}(\Lambda^0_b \to p\pi^-) = -0.03 \pm 0.17\ (stat.) \pm 0.05\ (syst.).$$

http://www-cdf.fnal.gov/physics/new/bottom/071018.blessed-ACP_Lambdab_ph